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DIVISION OF ENVIRONMENTAL HEALTH

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JUN 22 1990
DIVISION OF
OIL, GAS & MINING

June 14, 1990

Mr. Rick York, General Manager
Moab Salt, Inc.
P.O. Box 1208
Moab, Utah 84532

RE: November 10, 1989 Revised Conceptual Plan, Study of the Potential Salt Loading on Local Hydrology, Moab Salt, Inc.

Dear Mr. York:

We have reviewed the above document and our earlier comments of October 2, 1989. A few of our comments have not been completely addressed, and are attached for your reference.

As you know, our common goal is to prevent the loss of your product to the environment. Since our last correspondence we have become aware of an electrical technique to detect leaks in synthetically lined ponds. We have attached it for your review, with the hope that you will consider its use at your facility. We believe that by testing the evaporation ponds for leaks on a regular basis and repairing the liners as necessary, we can maintain your product in your process circuit and minimize the release of contaminants to the environment.

Furthermore, such leak detection efforts and conscientious operation and maintenance of the ponds will accomplish much more in protecting the environmental than attempting to recover the brines after they have seeped away. With this in mind, we propose the following approach for the evaporation ponds:

1. Evaluate the electrical leak detection method for use at Moab Salt's evaporation ponds.

2. Determine an acceptable timetable for testing and repairing the liner, if necessary, in each of the ponds.

3. Develop an acceptable plan for ongoing operation and maintenance of the evaporation ponds which includes periodic leak detection testing of the liners.

If Moab Salt is successful in preventing leakage from the evaporation ponds, the need for sampling and controlling contaminated runoff will be avoided. Brine recovery, including recovery wells in the canyon collection system, however, may be necessary until existing seepage can be captured. If Moab Salt can implement an acceptable leak testing process, we would be willing to forego the runoff quality and water balance studies for the evaporation ponds and the monitoring wells proposed for the canyon collection system.

In addition to maintaining the brine product in your process circuit, a leak detection approach has other advantages for Moab Salt, including:

1. It allows you as to focus the expenditure of funds and environmental effort on the more-cost-effective means of prevention, rather than on recovery or cleanup.

2. It allows Moab Salt to evaluate each pond to determine the merits of and need for repair, rather than assume that all the ponds must be relined.

3. It will allow the evaporation ponds to obtain Construction Permit approval and regain compliance with the regulations (see UAC R448-1-2).

Regardless of whether or not Moab Salt can implement an acceptable leak detection process for the evaporation ponds we request that the Conceptual Plan be finalized and implemented during the third quarter of 1990.

We would appreciate a prompt response concerning this approach for the evaporation ponds. If you have any questions or comments please call Loren Morton or Steve McNeal at 538-6146.

Sincerely,

Jay B. Pitkin

for Don A. Ostler, Director
Bureau of Water Pollution Control

Attachments

cc: Holland Shepard, DOGM
Oliver Gushee, Gushee, Pruitt & Fletcher
Dave Ariotti, S.E. District Health Department

Attachment

Bureau Comments On:
Moab Salt November 10, 1989 Revised Conceptual Plan,
Study of the Potential Salt Loading on Local Hydrology

1. Conceptual Plan and Construction Permit Approval - a conceptual plan implies that it is preliminary, incomplete, or not ready to implement. Based on the noncompliance due to the lack of Construction Permits for the evaporation ponds, salt storage area, domestic wastewater system, brine lake, and the leaking condition of the evaporation ponds we believe that it is important to bring your facility back into compliance with the regulations as soon as possible (see UAC R448-1-2). Therefore, we would like your plan to include:

   A. The objective of obtaining a Construction Permit approval for the evaporation ponds, salt storage area, domestic wastewater system, and brine lake in accordance with UAC R448-1-2, and

   B. Sufficient detail so that the plan is complete and ready to implement as soon as possible.

2. Unaddressed Comments

   A. Evaluation of Historical Data (Section 2.3) - review of the historical data must include all the field and laboratory parameters found in Section 2.1. If some parameters are not available from the existing data, these should be noted.

   B. Local Springs (Section 2.4) - the additional spring inventory should only need to be carried out in the drainage where the proposed surface runoff sampling points Nos. 1 and 10 are located, since seeps in the other drainages have already been located (see seeps on Figure 2, "Geology and Ground Water Hydrology in the Vicinity of the Texasgulf Chemicals Company Potash Solution Mine, Ground and San Juan Counties, Utah", by Peter Huntoon, July 19, 1985). Any seeps that may soon be identified and all the formerly identified seeps should be sampled for ground water quality, and listed in the plan. Sampling should continue for as long as necessary, as determined by the Executive Secretary.

   C. Water Balance (Section 3.1)

      1) Evaporation Rate - the evaporation rate is critical to calculation of the water balance; therefore, Moab Salt should independently measure the evaporation rate of the brine in the field, at each facility i.e. at the evaporation ponds and the brine lake. If this is not possible Moab Salt must justify how the data from the State climatologist is representative of conditions at the site, including how the data is representative of the evaporation of a highly saline brine. Measurement of the evaporation rate at the evaporation ponds may not be necessary if leak detection is employed.

2) Brine Lake Volume - Moab Salt should provide more detail on how the brine lake volume will be determined.

D. Canyon Collection System (section 3.2) - monitoring wells installed into the alluvium to measure brine recovery efficiently should be constructed and monitored before operation of the renovated recovery wells. However, if an acceptable leak detection method is employed at the evaporation ponds, these monitoring wells will not be required.

E. Evaporation Ponds (Section 3.3)*

1) Ranking for Relining - the plan does not include a ranking for pond relining, as per our October 2, 1989 request.

2) Pond Design Life - we are awaiting the results of the manufacturer's testing of samples from your liner, in anticipation that this data will allow you to estimate the remaining liner life. This may also effect the proposed schedule for relining the ponds.

F. Brine Lake (Section 3.4)

1) Reservoir Grouting - we are aware of the contents of your May 18, 1988 submittal regarding the July, 1962 remedial grouting of the left abutment of the tailings dam. During discussions with your staff on June 7, 1990 we learned that you have no records of any grouting of faults or joints in the reservoir area. Therefore, we are only able to conclude that no such grouting was undertaken in the reservoir or salt storage areas, either during or after construction of the tailings dam and reservoir. This reinforces our concern for seepage losses from these areas.

2) Water Balance and Hydrogeologic Studies - we share your concern regarding the accuracy of the water balance that you raised in Section 3.1. For this reason we continue to maintain that other studies may also be needed in order to adequately assess any seepage losses from the brine lake. We were and continue to be in general agreement with your May 18, 1988 proposal to conduct VLF/EM surveys, installation of monitoring and pumping wells, pump tests, and ground water computer flow modeling.

G. Salt Storage Area - the plan still does not address seepage losses from the salt storage area. What efforts will you incorporate to measure these losses? Are there any steps Moab Salt can take to prevent said brine losses from this area?

Detection and Location of Leaks in Geomembrane Liners Using an Electrical Method: Case Histories

Daren L. Laine
Michael P. Miklas, Jr.
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ABSTRACT

A field-proven electrical technique, developed at Southwest Research Institute, San Antonio, Texas, is commercially available to detect and locate leaks in geomembrane liners. The electrical technique is used to inspect 100% of the geomembrane material that is covered by a conducting liquid. A voltage applied across the liner produces a uniform electrical potential distribution in the liquid or soil above the liner when no leaks are present in the geomembrane. If leaks are present, they are detected and located by searching for localized anomalies in the potential distribution caused by current flowing through the leak in the geomembrane liner. Sixty-one new or in-service geomembrane-lined waste storage facilities were investigated using the electrical leak location method. An average of 3.2 leaks per 10,000 ft^2 were located with a range of 0.3 to 5 leaks per 10,000 ft^2 of liner surveyed. Many leaks were located in new installations that had been tested using conventional inspection tests.

INTRODUCTION

Survey Method

Figure 1 shows a diagram of the Southwest Research Institute electrical leak location method which illustrates the technique described in this paper. When no leaks are present, the high electrical resistivity of the geomembrane liner material will prevent electrical current flow from the liquid in an impoundment to the earth ground or leak collection zone beneath the geomembrane liner. When a voltage is impressed across a geomembrane liner with no leaks, a relatively uniform potential voltage distribution is found in the liquid or soil cover above the liner. If a leak exists in the liner, conductive fluid will flow through the leak establishing a path for electrical current. An anomaly in the measured electrical potential is generated in the immediate vicinity of the leak through which electrical current is flowing. Leaks can be accurately located to less than 1 in. by searching for the point of highest electrical potential.

Survey Equipment

The equipment used in a manual leak location survey consists of a DC power source, lightweight man-portable electronic detector, scanning probe and associated instrumentation as shown in Figure 2. The probe is most conveniently used while wading in the liquid. However, with an extension, it can be used from a floating platform in deeper liquid applications.

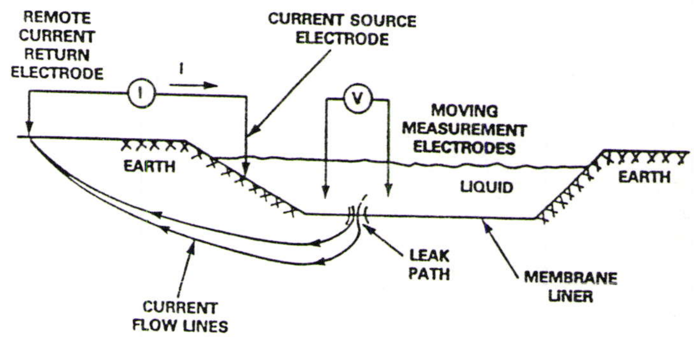

Figure 1
Diagram of the Electrical Leak Location Method

Figure 2
Manual Leak Location Equipment Consisting of an Electrode Probe and Electronics Unit

MANUAL LEAK LOCATION SURVEY IN LIQUID IMPOUNDMENT

To conduct a manual leak location survey, a minimum of 12 in. of a conducting liquid and a maximum of 30 in. of conducting

From: Superfund '89 — Proc. of the 10th Natl. Conf. Nov. 27-29, 1989, Wash D.C. (HMCRI) liquid (preferably fresh water) must cover the liner. Filling the impoundment to the operating depth with fresh water is recommended to hydrostatically load the liner prior to the leak location survey. Testing the liner after hydrostatically loading it is a valid method to determine if the liner will perform satisfactorily under the intended operating conditions. The water is then lowered in stages as the side slopes of the impoundment are electrically tested. After the water has been lowered to 30 in. in depth, the bottom floor area is surveyed.

In surveying a double liner impoundment, provisions must be made to ensure that the material between the geomembrane liners provides electrical conduction to a return electrode placed in the leak collection zone. The test is best accomplished by flooding the leak collection zone with fresh water. To provide electrical contact to the leak collection zone, a stainless steel return electrode with connecting wire is placed in the zone prior to the installation of the primary liner. The return electrode also can be temporarily placed in the leak collection drain pipe if access is available. In both cases, the return electrode must be covered with water.

Air vents should be provided along the perimeter edges of the primary liner near the top of the berm to vent air trapped between the liners. This procedure will help prevent damage to the liner caused by trapped air floating the liner during flooding of the leak collection system. Impoundments that use sand as the material in the drainage layer usually do not require water flooding of the leak collection zone. This is because the sand contains sufficient residual moisture to allow electrical current flow in the sand drainage layer. However, a permanent stainless steel electrode placed in the sand drainage layer prior to the placement of the primary liner will greatly facilitate electrical leak location surveys.

Electrical conduction paths, other than leaks, such as steel piping, piers, fasteners and battens must be electrically isolated for best leak location results. Certain preparations such as rubber packers in inlet and discharge pipes will prepare most geomembrane lined impoundments for a successful leak location survey. The electrical leak location survey method can be most effectively and economically applied if the impoundment or landfill is designed such that electrical conduction paths between the liquid in the impoundment and the earth ground are eliminated or can be electrically insulated.

SURVEYS OF SOIL-COVERED GEOMEMBRANES

A protective soil cover often is placed over the primary geomembrane liner of landfills to protect the liner from mechanical damage when placing the waste material in the landfill. In addition, a sand drainage layer often is used as the drainage medium in the leak detector zone of double liner installations. However, during the placement of the protective soil cover or the sand drainage layer, the liner can be damaged by the equipment used to place the soil cover, tools used to spread the material, sharp rocks in the soil or by a variety of other mechanical mechanisms. Often the mechanical damage to the liner is undetected and covered by the placing of the protective soil cover. The electrical leak location survey technique has been successfully adapted to locate leaks in geomembranes covered with up to 2 ft of a protective soil cover or sand drainage layer. Leaks were located and later verified beneath protective soil cover, sand drainage layers and thin sediment layers at several sites surveyed.

A protective soil cover or sludge cover over a geomembrane can decrease the effectiveness of a leak survey in three ways:

(1) The strength of the signal received may be reduced because of inhomogeneities in the soil cover or sand drainage layer
(2) The ability of the electrodes to detect leak signals is decreased because of the dissimilarity of the soil and water medium contacting the electrode, resulting in undesirable transient signals caused by polarization of the electrodes
(3) The scanning probe cannot be scanned close to the geomembrane liner

The first condition is solved by systematically conducting the survey on an established survey grid and recording the current signature every 24 in. The acquired data are analyzed in the field and a plot of anomalies is produced which allows for a resolution of the leak locations. The dissimilarity or polarization problem is overcome by using specially designed electrodes to eliminate electrode polarization.

TYPES OF FACILITIES AND MATERIALS SURVEYED

Facility Types Surveyed

The electrical leak location survey method was used to survey geomembrane lined facilities ranging in size from 970 to 584,800 ft^2. The facilities tested include:

- Primary and secondary liners at landfills
- Concrete vaults for solid waste storage
- Wastewater storage ponds for sewage treatment facilities
- Above ground steel tanks for storage of hazardous materials
- Brine storage impoundments
- Descaling ponds for natural gas transmission companies
- Cooling water ponds

Materials Surveyed

Approximately 92% of all materials by area surveyed were high density polyethylene (HDPE). At installations lined with HDPE, the predominant material thickness was 60 mil. The remainder of the HDPE material had a thickness of 80 or 100 mils. The other liner materials were polyvinyl chloride (PVC), oil-resistant polyvinyl chloride (XR-5) and oil-resistant chlorosulfonated polyethylene (OR-CSPE). Generally, the seams at a given facility had been inspected using conventional inspection techniques such as visual inspection, air-lance, spark testing or vacuum box prior to the electrical leak location survey. After the electrical leak location survey was completed, the presence of the leaks detected and located by the electrical method was verified at several of the facilities using the vacuum box technique.

DISCUSSION OF LEAKS DETECTED AND LOCATED

Leak Statistics

Sixty-one sites with an approximate total area of 4,368,785 ft^2 of liner material have been commercially surveyed. Tables 1, 2 and 3 present a summary of all the commercial leak surveys conducted to date using the electrical method developed at Southwest Research Institute. A total of 1409 leaks were located at the 61 sites surveyed which equates to an average of 3.2 leaks/10,000 ft^2 of liner material inspected.

Figures 3 through 7 are plots of the data as a function of the area surveyed and the leak location on seams or sheet, total number of leaks or area ratio of the leaks located. Figure 7 is a plot of the number of sites surveyed vs. the area ratio of the leaks located which indicates that there may be between 0.3 and 0.5 leaks/10,000 ft^2 of geomembrane liner.

Leaks on Side Slopes

The side slopes were surveyed at approximately 25% of the liners surveyed. The majority of leaks on the side slopes occurred on the seams. At the facilities where the side slopes were tested, leaks on the side slopes comprised approximately 20% of the total leaks located.

Leaks in the Bottom of the Liner

Leaks on the bottom of liquid impoundments were found in the parent material, field seams and factory seams. Eighty-seven

Table 1
Leak Detection and Location Survey Data for Impoundment Where the Bottom Floor Area was Surveyed.

SURVEY NO.	SIZE SQ. FEET	TOTAL LEAKS	LEAKS LOCATED IN BOTTOM	SEAM	SHEET	LEAKS PER 10,000 SQ. FEET
1	958	2	2	2	0	20.9
2	958	3	3	3	0	31.3
3	958	3	3	3	0	31.3
4	1,000	4	4	3	1	40.0
5	1,798	0	0	0	0	0.0
6	2,625	6	6	6	0	22.9
7	3,000	21	21	21	0	70.0
8	3,000	4	4	4	0	13.3
9	3,200	0	0	0	0	0.0
10	4,951	0	0	0	0	0.0
11	4,951	17	17	17	0	34.3
12	4,951	2	2	2	0	4.0
13	5,175	2	2	1	1	3.9
14	7,007	4	4	4	0	5.7
15	12,600	7	7	7	0	5.6
16	18,346	50	50	35	15	27.3
17	26,016	7	7	7	0	2.7
18	26,016	4	4	4	0	1.5
19	27,297	8	8	6	2	2.9
20	32,292	25	25	25	0	7.7
21	43,560	2	2	2	0	0.5
22	45,345	4	4	4	0	0.9
23	50,000	6	6	6	0	1.2
24	50,400	193	193	188	5	38.3
25	54,500	29	29	18	11	5.3
26	55,025	12	12	12	0	2.2
27	58,900	8	8	6	2	1.4
28	62,500	21	21	19	2	3.4
29	64,583	29	29	21	8	4.5
30	65,340	56	56	55	1	8.6
31	65,369	6	6	6	0	0.9
32	65,369	7	7	5	2	1.1
33	65,369	5	5	3	2	0.8
34	65,500	7	7	5	2	1.1
35	65,500	5	5	3	2	0.8
36	74,088	20	20	19	1	2.7
37	82,500	18	18	15	3	2.2
38	87,120	8	8	7	1	0.9
39	87,120	17	17	17	0	2.0
40	99,050	18	18	14	4	1.8
41	135,036	17	17	16	1	1.3
42	150,781	64	64	46	18	4.2
43	152,460	2	2	2	0	0.1
44	152,460	7	7	7	0	0.5
45	157,584	12	12	10	2	0.8
46	164,085	18	18	16	2	1.1
47	362,690	51	51	37	14	1.4
TOTALS	2,769,336	811	811	709	102	2.9

Table 2
Leak Detection Data for Impoundment with the Side Slopes and Bottom Floor Area Surveyed.

SURVEY NO.	SIZE SQ. FEET	TOTAL LEAKS	LEAKS LOCATED IN BOTTOM	SEAM	SHEET	SIDE SLOPE	LEAKS PER 10,000 SQ. FEET
1	9,620	16	12	14	2	4	16.6
2	12,540	16	12	12	4	4	12.8
3	24,000	40	33	33	7	7	16.7
4	24,272	47	31	46	1	16	19.4
5	25,000	22	10	15	7	12	8.8
6	25,000	15	7	10	5	8	6.0
7	35,291	42	31	33	9	11	11.9
8	42,022	14	7	12	2	7	3.3
9	50,000	4	4	3	1	0	0.8
10	51,000	20	13	19	1	7	3.9
11	62,500	50	26	44	6	24	8.0
12	130,680	192	183	183	9	9	14.7
13	522,720	41	31	31	10	10	0.8
14	584,804	79	54	61	18	25	1.4
TOTALS	1,599,449	598	454	516	82	144	3.7

Table 3
Survey Data for All Impoundments Inspected.

	SITES	TOTAL AREA	TOTAL LEAKS	LEAKS LOCATED IN BOTTOM	SEAM	SHEET	SIDE SLOPE	LEAKS PER 10,000 SQ. FEET
BOTTOM AREA ONLY	47	2,769,336	811	811	709	102	N/A	2.9
BOTTOM AND SIDE AREA	14	1,599,449	598	454	516 *	82	144	3.7
TOTAL	61	4,368,785	1,409	1,265	1,225	184	144	6.7

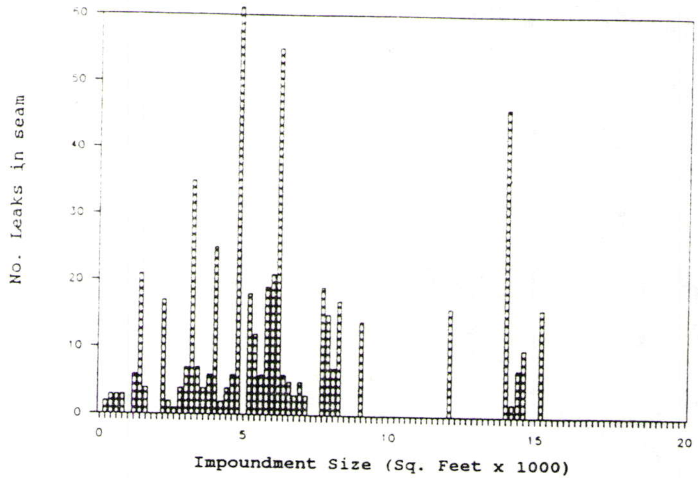

Figure 3
Histogram of Total Leaks Located vs. Bottom Floor Area Surveyed

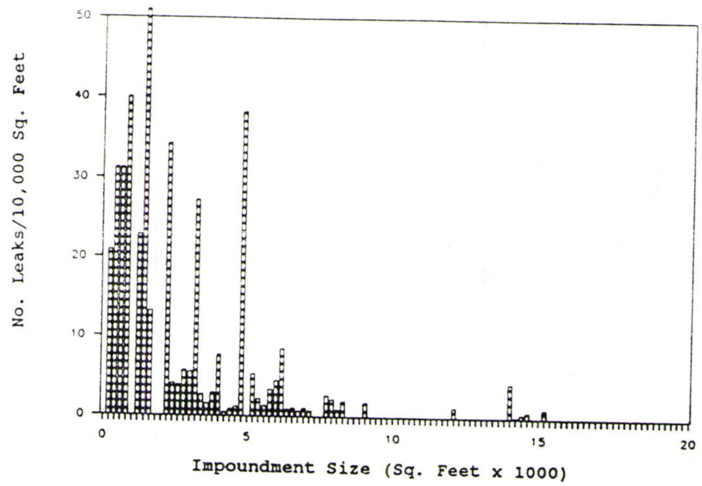

Figure 4
Histogram of Leaks per 10,000 ft² of Liner Surveyed

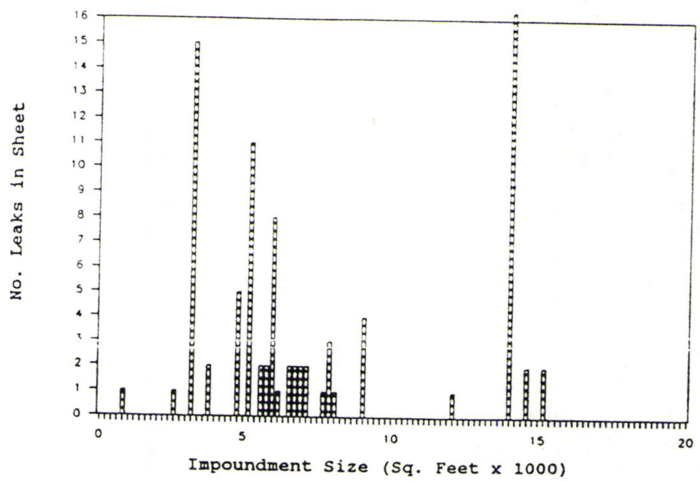

Figure 5
Histogram of Leaks in the Parent Material vs. Impoundment Size

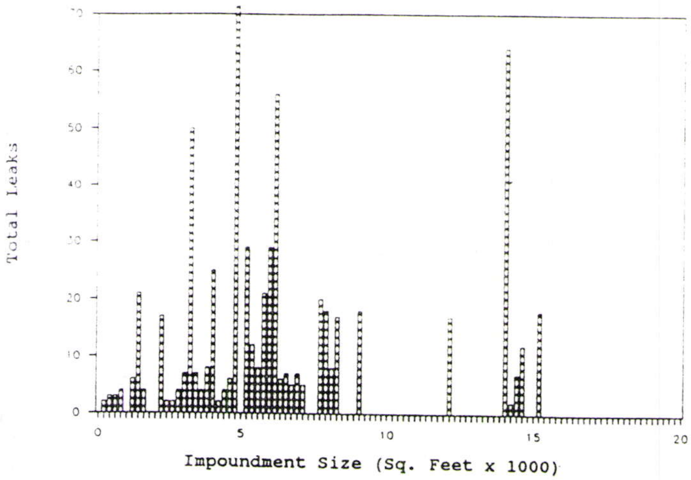

Figure 6
Histogram of Leaks in Seam vs. Impoundment Size

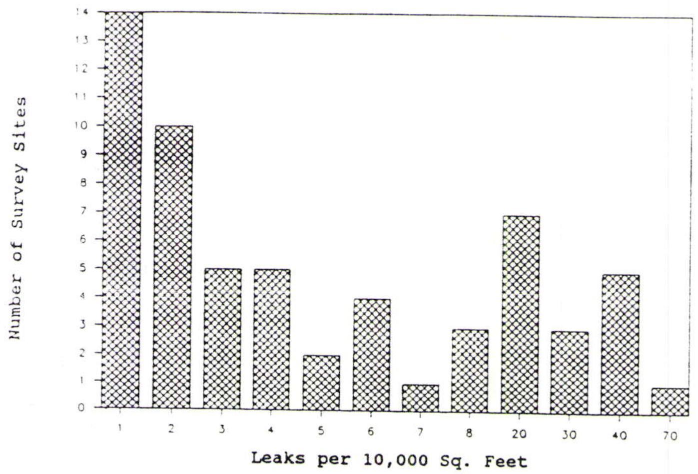

Figure 7
Histogram of Number of Sites Surveyed vs. Number of Leaks Located per 10,000 ft^2 of Geomembrane Liner

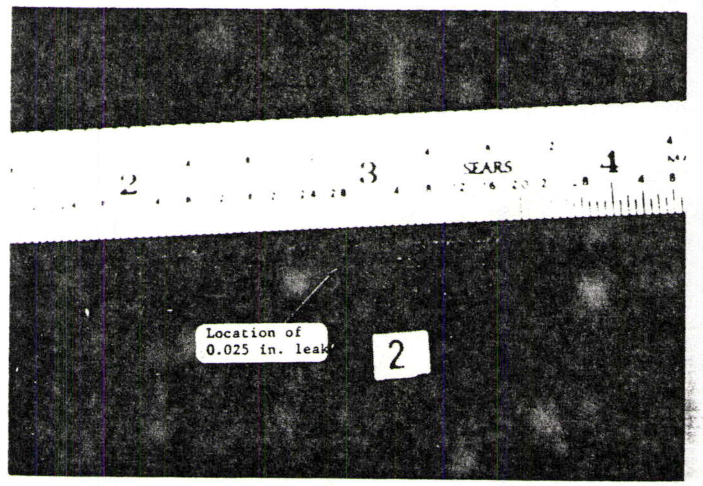

Figure 8
Leak in HDPE Seam. Approximate Leak Size 0.025 In.
(Note: Leak not apparent in reproduced photograph.)

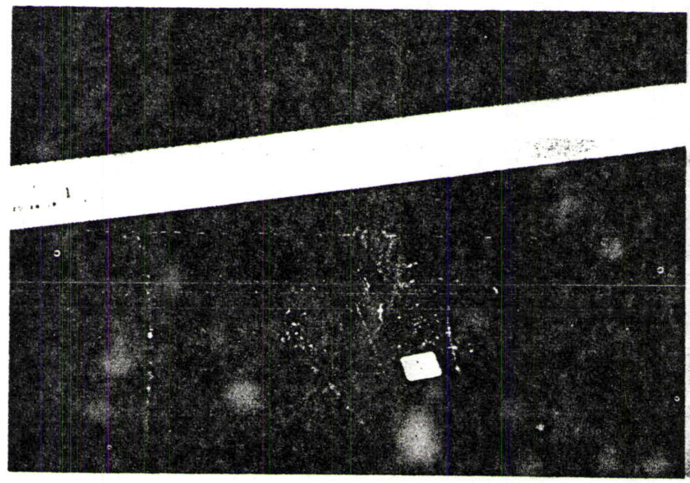

Figure 9
Leak in Parent Material

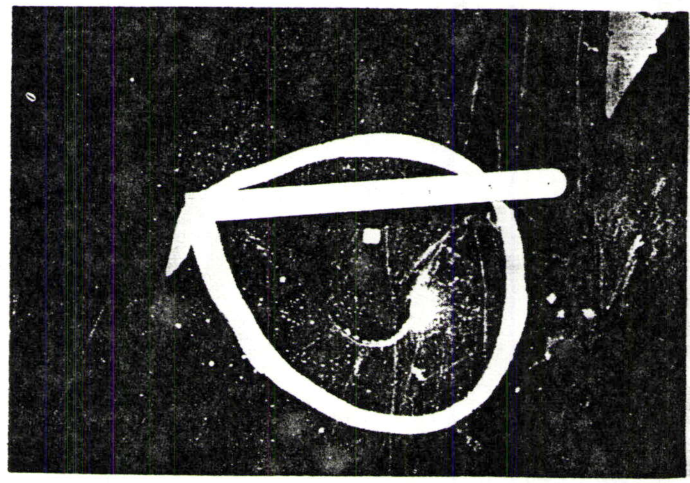

Figure 10
Large Leak in HDPE Parent Material

percent of the leaks were in seams, and the remaining 13% were in the parent material. Figures 8 and 9 show examples of seam leaks detected with the Southwest Research Institute electrical leak location system. Leak sizes and shapes ranged from relatively circular holes from less than 0.025 to 1 in. in diameter, to slits from 0.25 to 12 in. long, to gashes and gouges up to 6 by 8 in., to evidently tortuous paths through seam welds.

Leaks in Parent Material

The leaks in the parent material generally can be attributed to accidental damage from equipment or tools, crescent-shaped cracks due to equipment being dropped, slits due to razor-edged tools cutting the liner, burns from cigarettes, gashes and gouges. Figures 10 and 11 show typical leaks in the parent material. Some of the leaks in the parent material probably were caused by improper material handling or wind buffeting. Many leaks in the parent material of installations with a protective soil cover appeared to have been created during the application of soil cover over the liner.

The observed ratio of parent material leaks to seam leaks may be slightly less than actual because the seams are double-checked during the leak location survey process. While rechecking the seams, the search probe tip is scanned within 1 in. from the leaks in the seams. However, during the general survey of the geomembrane, the parent material is swept at 12 in. intervals placing the electrical probe as much as 6 in. from a potential leak point. Because the probe tip is approximately six times closer to potential leaks when surveying the liner seams, it is probable that very small leaks found in the seams are not detected in the parent material.

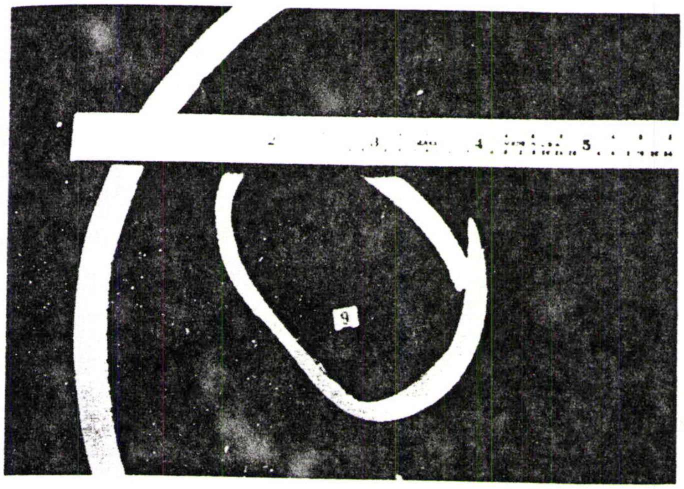

Figure 11
Cut in HDPE Parent Material

Leaks in Seams

Inadequate field seaming appears to be the primary cause of leaks in geomembrane lined impoundments. Eighty-seven percent of the total number of leaks were in field welded or bonded seams. Many of the leaks occurred at T-joints, patches and at seams in highly-stressed areas such as at the base of the sideslope. Some leaks were found in seams which previously had been repaired and tested. Figures 12, 13 and 14 show typical leaks located in seams. Leaks may not develop in the seams until a hydrostatic load is placed upon the liner. Cases were documented where obviously poor seaming techniques resulted in seams failing indiscriminately after repair and hydrostatic loading. In such cases, it is suggested that the entire liner installation be redone.

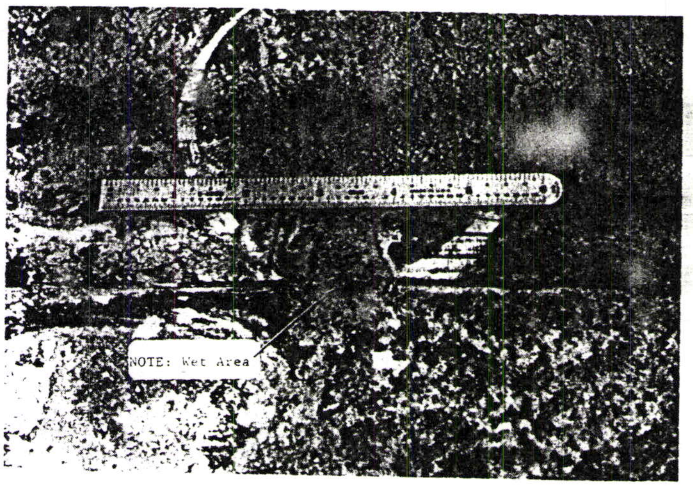

Figure 12
Leak in Seam

Leaks Associated with Penetrations and Structures

In some facilities, numerous leaks were found around penetrations or structures in an otherwise excellent field installation. Many designs incorporate complex seam requirements when attempting to isolate drainage cribs, separation walls, concrete sumps, concrete pads and other structures. Where such structures are necessary, the electrical method may be the only method which can be applied to test for leaks.

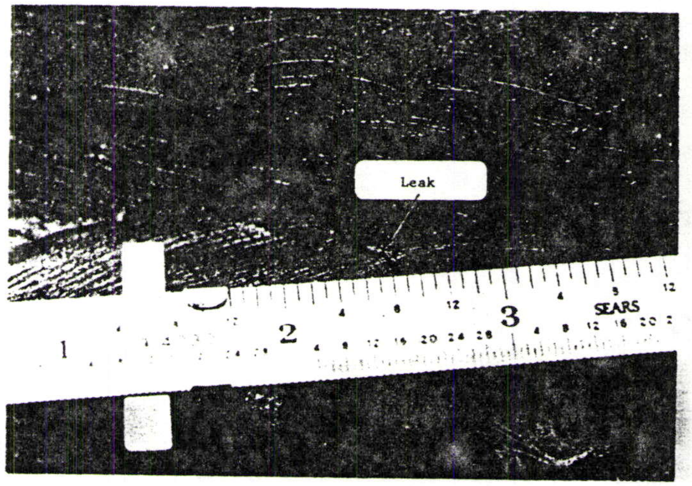

Figure 13
Leak in Seam After Grinding, Just Prior to Repair

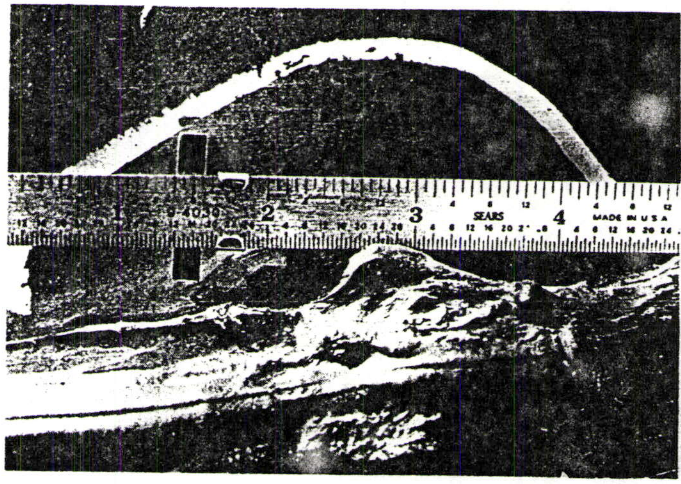

Figure 14
Leak in Seam Where Seaming Material Did Not Bond to Sheet

Leaks Associated with Material Types

Because of the limited use of materials other than HDPE in the facilities tested by the Southwest Research Institute electrical method, it is not possible to formulate any valid conclusions on the relationship of material type to numbers and types of leaks.

Leaks Beneath Soil Covers and Sludge

The Institute has successfully located leaks beneath installed soil cover up to 2 ft thick. Leaks have been found beneath chemical precipitate sludges, but the application of the electrical method in the sludge environment is extremely tedious and demanding. The leaks found beneath soil covers have included seam leaks and leaks in the parent material apparently caused by the heavy equipment which was placing the protective soil cover material. Figures 15, 16 and 17 show leaks located under 2 ft of sand place over the primary geomembrane liner. No significant numerical relationships between leaks, leak occurrence and types of leaks can be developed on leaks discovered beneath soil covers because of the limited field testing experience in such environments.

CONCLUSIONS

The electrical leak location method is a very sensitive, accurate and valid method for locating leaks in geomembrane liners. Leaks were found in every liner surveyed except for three liners that were less than 500 ft^2 in area. Leaks were located in liners that had been rigorously tested using one or more of the conventional methods for testing geomembrane liners.

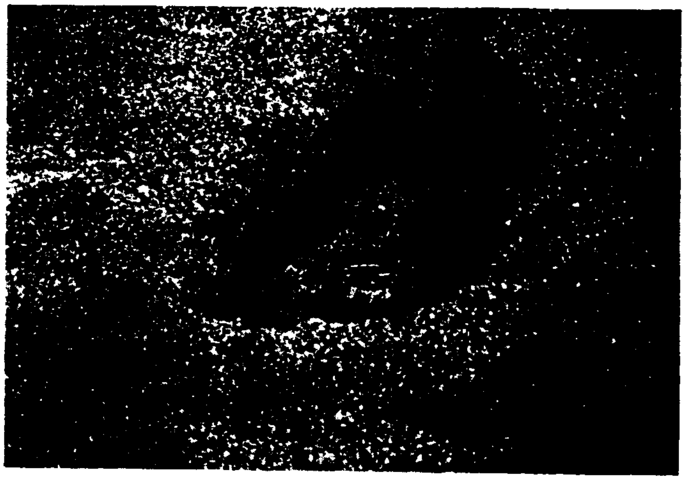

Figure 15
Leak Under 2 ft of Protective Sand Cover

Figure 16
Mechanical Damage to Liner Under 2 ft of Sand Cover

The number of leaks per 10,000 ft^2 of surveyed area typically ranged from 0.3 to 5 with an average density of 3.2 leaks/10,000 ft^2 of geomembrane liner. Several liners had greater than 20 leaks/10,000 ft^2 of area surveyed.

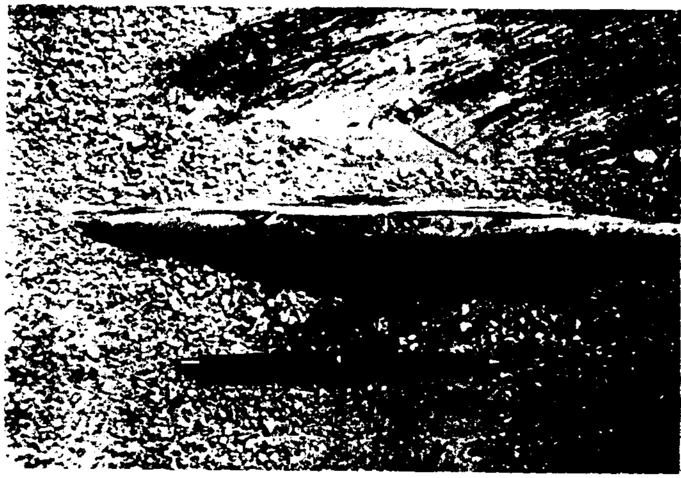

Figure 17
Tear in Liner Covered with 2 ft of Sand

The density of leaks generally decreases as the liner size increases. Possible explanations for this are:

- Smaller installations have proportionally more complex features such as corners, sumps and penetrations
- Small installations tend to have higher proportions of hand seaming
- Larger installations tend to have better QA/QC programs
- Larger installations generally receive proportionally less traffic

From our experience, and knowledge of the history of some of the liners surveyed, the major factors for minimizing the number of leaks in geomembrane liners in the general order of importance are: the professionalism and skill of the seaming machine operator; environmental factors such as moisture, temperature and wind; simplicity of the liner design; thickness and weldability of the liner material; and liner care and handling procedures.

The electrical leak location method has demonstrated that geomembrane installations can benefit from an electrical method leak location survey as a part of the construction quality assurance program. Pre-service testing of new installations using the electrical leak location method will enhance the overall performance of the containment facility.

= 13.9 leaks/acre

Understanding Electrical Leak Location Surveys of Geomembrane Liners and Avoiding Specification Pitfalls

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ABSTRACT

The electrical leak location method developed under contract for the U.S. EPA is now being put to use in many commercial applications, and several contractors are providing electrical leak location services. The commercial surveys conducted to date have been overwhelming successes in that many leaks have been efficiently and accurately located in installations that had been previously tested certified leak-free environment conventional methods. The results of these surveys lead to the speculation that a pre-service electrical leak location survey should be performed on every geomembrane-lined landfill and impoundment before the installation is considered complete and ready for use.

The electrical method detects areas of localized electrical current flow through leaks in the otherwise insulating liner. A voltage source is connected to an electrode in water covering the liner and to a grounded electrode. Leaks are located by searching for the localized areas of relatively high electrical potential in the water caused by current flowing through a leak. The electrical leak location method can be used in liquid impoundments and for a pre-service inspection of solid waste landfills. The testing method will not damage the liner.

As with any new technology, many people in the environmental industry want a better understanding of the principles, capabilities and the proper application of the method. Specifiers of electrical leak location surveys must have this knowledge to specify the most effective and economical surveys. The objective of this paper is to provide important up-to-date information to meet this need.

INTRODUCTION

Geomembrane liners, also known as flexible membrane liners (FMLs), synthetic liners and membrane liners, are sheets of polymeric materials fabricated in a factory and seamed together at the field site to form a continuous liner. Installation can result in punctures or separated seams, causing loss of the liner's physical integrity. Damage also can be accidentally caused by heavy machinery used to place protective bedding material on the liner.

An electrical leak location method was developed and tested under contract for the U.S. EPA. This method has been demonstrated to be the most sensitive, reliable and valid method for locating leaks in geomembrane liners of waste landfills and impoundments. The electrical leak location method is now being widely applied and several contractors are providing electrical leak location services. Several technical references for the electrical leak location method are listed in the Bibliography.

Results of Leak Location Surveys

Southwest Research Institute has surveyed 56 geomembrane-lined storage facilities for leaks using the electrical leak location equipment. The total liner area surveyed was more than 4,4,000,000 ft². The sizes of these installations ranged from less than 1000 ft² to more than 500,000 ft² and included both double- and single-lined impoundments and landfills. Almost all of the liners were in new installations. Most of the liners were constructed of high density polyethylene (HDPE), but some were chlorosulfonated polyethylene (CSPE) and polyvinyl chloride (PVC).

Leaks were found at all of the sites except for two sites with small liners. The average density of leaks was approximately one leak per 3200 ft² 13 leaks per acre. Although most of the leaks occurred in field seams, a significant number (more than 15%) were found in the parent material. The high percentage of leaks found in the seams is partly attributed to the fact that some very small seam leaks are found when the seams are surveyed a second time with the leak location probe on the seam.

Typical installations had from four to 12 leaks per acre. Installation and field seaming problems were experienced on the liners with greater than 20 leaks per acre. Several of the liners had more than 50 leaks per acre.

Because some leak location surveys were initiated in response to a known leakage problem, a significantly higher number of leaks might be expected for these installations. However, the number of leaks at the installations with known problems were fewer than installations where the leak location surveys were performed for construction quality assurance purposes. The results of these surveys indicate that a pre-service electrical leak location survey should be performed on every geomembrane-lined landfill and impoundment.

TECHNICAL DISCUSSION

Theory of Operation

Figure 1 shows the basic electrical leak location method for locating leaks in a geomembrane liner. The principles of the electrical leak location method are relatively uncomplicated. A DC voltage is connected to electrodes placed in electrically conductive material above and below the liner. The impressed voltage produces a very low current flow and a relatively uniform electrical potential distribution in the water above the liner in areas with no leaks. If the liner has a leak, water flows through the leak and establishes an electrical current path through the liner. Leaks are located by searching for the localized areas of relatively high electrical potential in the water covering the liner. The increased current density near the leak is indicated as an anomaly in the measured potential. The electrical leak location method can be used in liquid impoundments, as a pre-service inspection of solid waste landfills and to locate leaks in the final cover for landfills or impoundments. This testing method does not damage the liner.

If applied properly, the electrical leak location method is very sensitive. To increase the leak detection reliability to a maximum level, leak

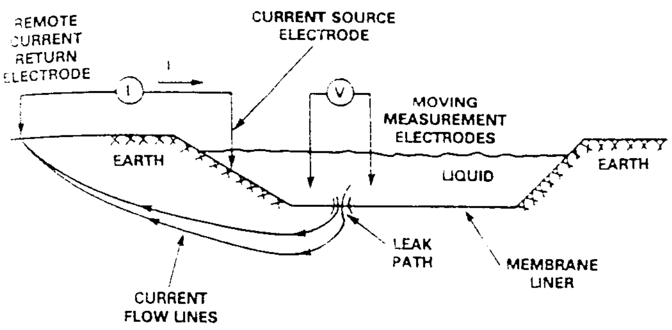


Figure 1
Diagram of the Electrical Leak Location Method

location surveys should be conducted with the maximum practical impressed voltage and detector sensitivity. Some of the leaks that are found are very small and may not leak significantly. Nevertheless, all detected leaks are located and marked for repair. The small leaks can indicate a weak seam that may fail with time or loading. In almost every survey, several larger leaks that require repair are found. The small leaks are repaired at the same time the larger leaks are repaired to increase confidence in the integrity of the liner.

Instrumentation

The manual leak location survey system consists of a lightweight, portable electrical probe and associated instrumentation. This system is for inspection of non-hazardous liquid-filled impoundments and for pre-service inspection of water-filled impoundments and landfills. Figure 2 illustrates the operation of the equipment.

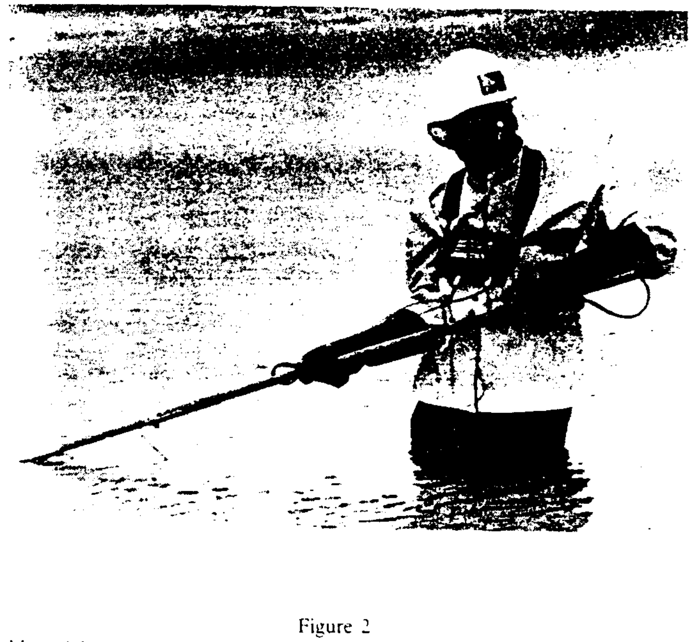


Figure 2
Manual Leak Location Equipment Consisting of an Electrode Probe and Electronics Unit

Figure 3 shows a typical detector electronics assembly. The battery-powered detector electronics provides an audio tone that varies in proportion to the measured signal so the operator is not required to continuously monitor the meter. Controls are provided to adjust the sensitivity, threshold and audio output level. Test buttons are provided to check the battery voltage and circuit operation. Connectors are provided to connect the detector probe outputs and an earphone for the audio indicator.

A source of DC power is used to impress a voltage across the geomembrane liner. Figure 4 shows an electrical leak location power supply with self-contained safety system. The leak detection sensitivity is proportional to the voltage output of the power supply. Batteries can be used for a safe low voltage power supply, but leak detection sensitivity will be decreased to a level where smaller leaks can not be detected and the leak detection reliability is decreased. For best results and sensitivity, a high voltage electronic power supply is used with a safety circuit. The high voltage power supply has an adjustable output level of up to 320 V DC. The safety circuit provides a measure of protection from accidental contact between earth ground and either power supply output or accidental contact across the power supply output. The safety circuits disconnect the power when a ground fault current is detected, or the output current momentarily increases or decreases due to possible human contact. A bright flashing warning light indicates that the power supply is energized.

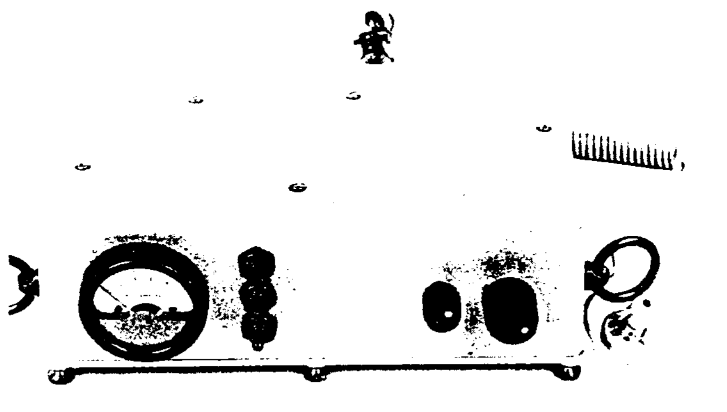


Figure 3
Leak Location Detector Electronics Assembly

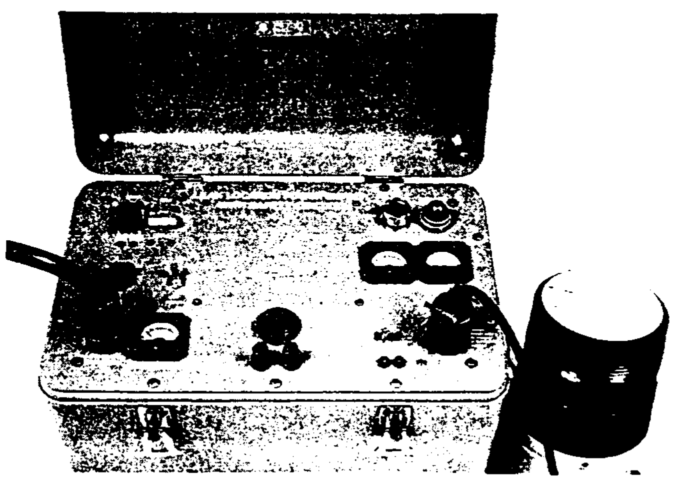


Figure 4
Leak Location Power Supply

The detector probe is a long pole with two electrodes. A cable connects the electrodes to the input of the detector electronics. The probe is most conveniently used while wading in the liquid but, with an extension, it can be used from a raft in deeper water applications. Surveys of the side slopes are accomplished using a probe with a long handle and small wheels to support the electrodes. The side slope area is surveyed by systematically lowering the probe down the slope and then pulling it up the slope.

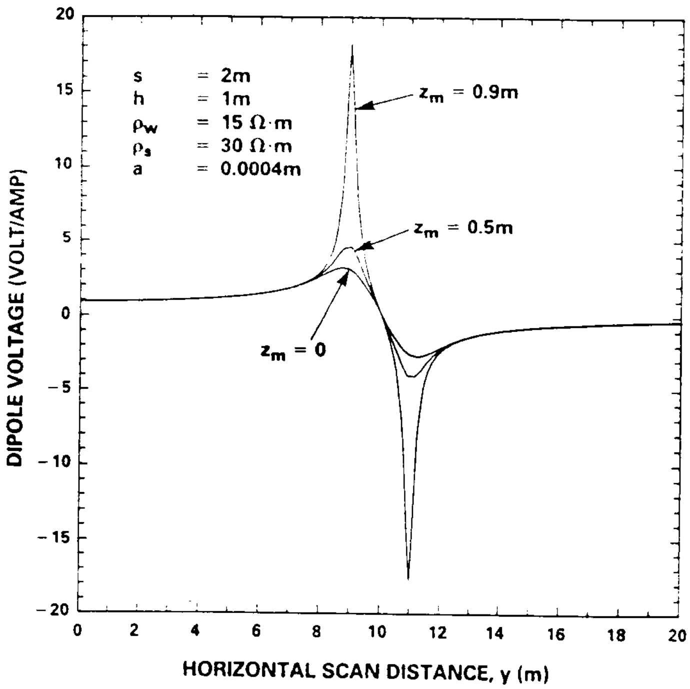
EFFECT OF MEASUREMENT PARAMETERS

Computer Model

A mathematical model was developed to investigate the performance capabilities of the electrical leak location method. The model accommodates various electrical and dimensional parameters for a lined impoundment or landfill. Model studies of the electrical leak location survey technique were conducted to characterize the performance of the method with various electrical parameters of the waste materials, the measurement electrode array geometry, the measurement electrode depths and proximity to the leak and the size and number of leaks.

Anomaly Effects of a Leak

Figure 5 shows a typical family of leak anomaly responses for horizontal detector electrodes that illustrate the effects of various measurement depths. The two peaks in the signal occur when the two electrodes pass within closest proximity of the leak. Figure 6 shows the amplitude of the leak anomaly for three different electrode spacings as the electrodes are scanned at various depths. A substantial improvement in detection sensitivity is obtained when the potential array is scanned closer to the leak. The computed leak responses and field experience affirm the practical importance of performing the survey measurements near the bottom of the impoundment.



Key: s = electrode spacing
h = depth of the water
ρ_w = liquid resistivity
ρ_s = underlying soil resistivity
a = leak radius
z_m = electrode depth
x = offset distance
y = distance along along scan line

Figure 5
Plot of the Leak Anomaly Versus Horizontal Electrode Depth

Figure 7 shows the anomaly response of a leak measured with a vertical electrode pair. The leak is located at the position indicated by the maximum response. Multiple leaks can be resolved with less ambiguity when vertical electrodes are used. Again, the computed leak responses point out the practical importance of performing survey measurements near the geomembrane liner.

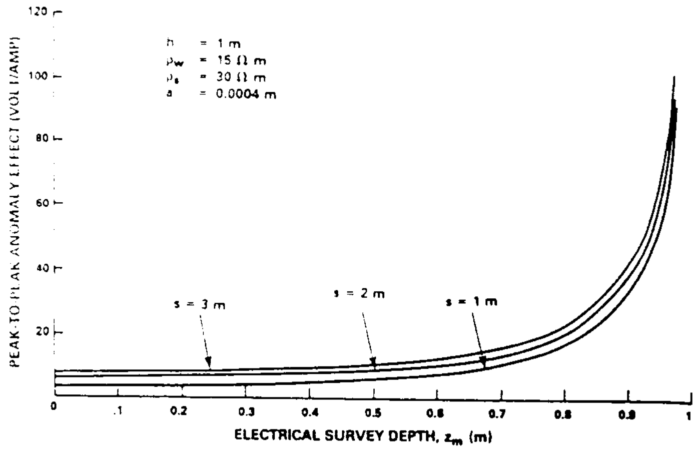


Figure 6
Leak Signal Amplitude Versus Survey Depth

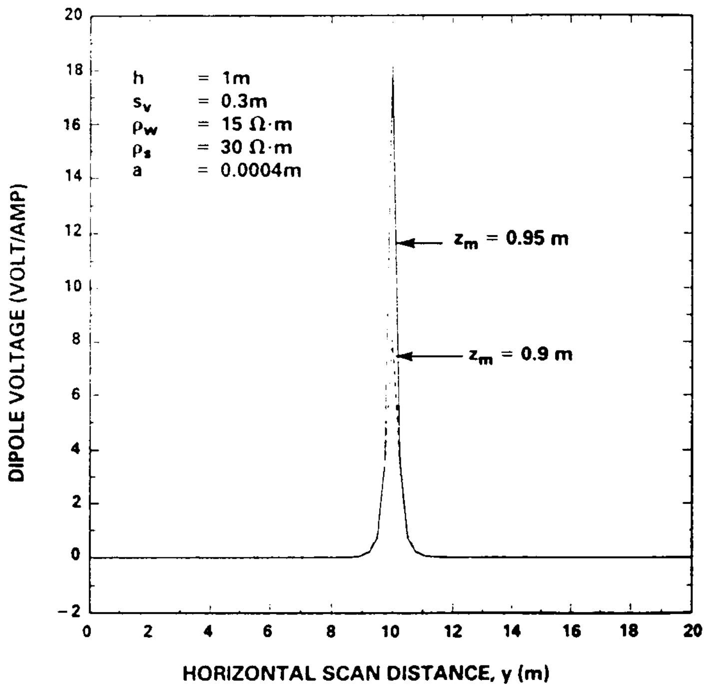


Figure 7
Leak Anomaly Characteristic for Vertical Electrodes

Effect of Measurement Electrode Spacing

In general, the amplitude of the measured leak signal increases as the electrode spacing increases. However, the increase is negligible when the electrode spacing is somewhat larger than the distance to the leak. This principle can be demonstrated by considering the equation for the voltage at some distance from the leak. The simplest mathematical model of a leak is to consider that the leak is a point current source in an infinite half space. If ρ_w is the resistivity of the water, I is the current and the distances from the leak to the two measurement electrodes, the measured voltage difference will be:

$$v = \frac{I\rho_w}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right].$$

Figure 8 shows the amplitude of the leak signal versus electrode separation when the electrode closest to the leak is 0.05, 0.1 and 0.2 meters with a current of 5 mamp and a water resistivity of 10 ohm-meters. The graph shows that little is gained by increasing the electrode spacing beyond approximately 0.3 meters.

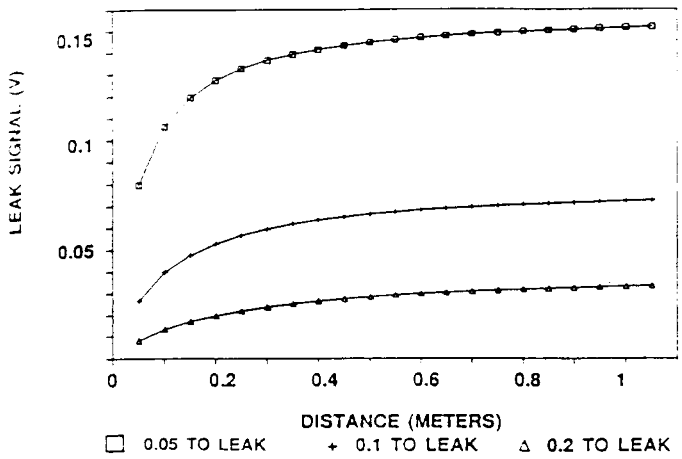


Figure 8
Leak Signal Amplitude Versus Electrode Separation

Effect of Water Resistivity

Figure 9 shows the amplitude of the leak anomaly for different values of water resistivity and water depth with the electrodes suspended midway in the water. These curves show that for a given amount of leak current, the leak detectability is increased essentially linearly with the resistivity of the water. The injected current must be increased to offset the effect of lower measured leak anomaly attributed to lower resistivity of the liquid. For constant current injection, the amplitude of the leak anomaly is essentially independent of the resistivity of the material under the liner.

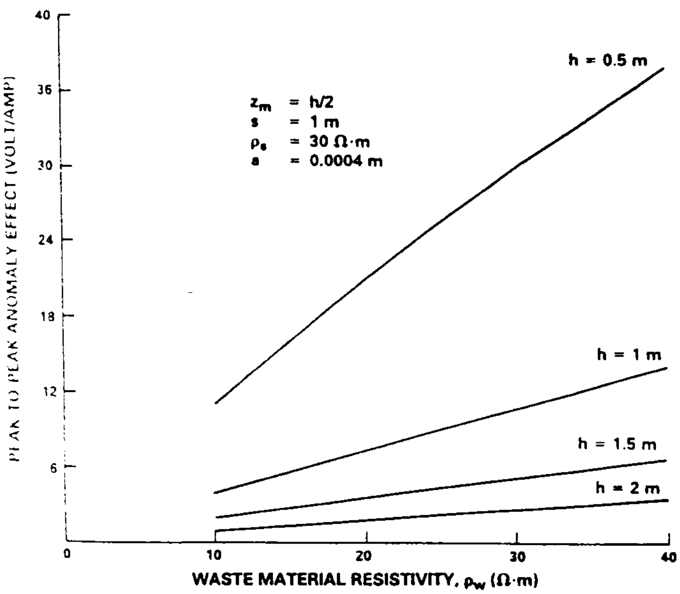


Figure 9
Leak Signal Versus Water Resistivity for
Various Water Depths

In practice, a constant voltage power source is used rather than a constant current source. Therefore, as the water resistivity is decreased, more current will flow through the leaks. However, the amount of current increase does not offset the decrease in signal level.

Effect of Offset Distance from Leak

The maximum allowable spacing between the lateral survey lines depends on the amount of current flowing through the leak and the sensitivity of the leak location equipment. To illustrate this characteristic, Figure 10 shows the amplitude of the leak anomaly for various electrode offset distances from the leak center as a function of the survey height above the liner. The amplitude of the anomaly decays rapidly as the offset distance is increased. These results indicate the importance of scanning the electrodes close to every point on the liner to obtain a high level of leak detection sensitivity.

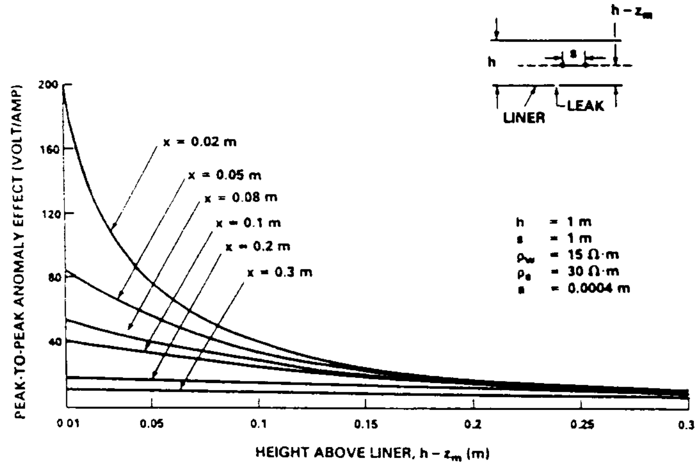


Figure 10
Leak Signal Amplitude Versus Height Above Liner for
Various Lateral Offset Distances

Leak Location Accuracy

The leak signal is at a maximum when the leak location electrode is touching the leak. Therefore, leaks are very accurately located by decreasing the sensitivity of the leak location electronics to a level where the point of maximum signal can be observed. The location of the leak can be essentially pinpointed in this way.

Effect of Leak Size

The size of the leak and the conductivity of the water essentially determine the amount of current flowing through the leak for a given impressed voltage. Because the leak signal is proportional to the amount of electrical current flowing through the leak, larger leaks are much easier to detect the smaller leaks. Experimental measurements of leak current versus leak diameter for circular leaks show that the amount of current flowing through the leak is approximately inversely proportional to the diameter of the leak. Other tests have been conducted to show that the shape of the leak has little effect upon the shape of the leak signature.

Effect of Liner Resistivity

Because the liner resistivity is many orders of magnitude greater than the resistivity of the water, the liner resistivity has no effect on the leak detection sensitivity. Laboratory tests have been conducted to show that the change in liner resistivity versus time for exposure to typical levels of acidity, alkalinity and dissolved salt content have negligible effect on the resistivity of the liner material.

Effect of Sediment Layer

The electrical leak location method is less sensitive for locating leaks in geomembrane liners with a sediment layer in the liquid. Physical model tests and field experience indicates the lower sensitivity and that the measurements are not as repeatable with sediment layers present.

The lower sensitivity occurs probably because the electrodes cannot be scanned close to the leak and the liquid shunts the measured potential field to some degree.

Effect of Soil Cover

Figure 11 is a plot of a measured leak anomaly versus depth of soil cover for a geomembrane liner when the electrodes are scanned directly over the leak. The diameter of the leak was 0.3 cm. Although the leak signal decreases rapidly with increasing soil cover thickness, the leak anomaly was easily detected for soil depths up to 0.6m. Figure 12 shows plots of the data with a soil thickness of 0.3m for scan lines offset from the leak. The leak is barely detectable when the electrodes are scanned on a line offset 0.6m from the leak. The signal can be improved by scraping the dry soil off the surface or inserting the electrodes into the more moist underlying soil. Figure 13 shows the decrease in the measured noise for these conditions with a soil thickness of 0.6m.

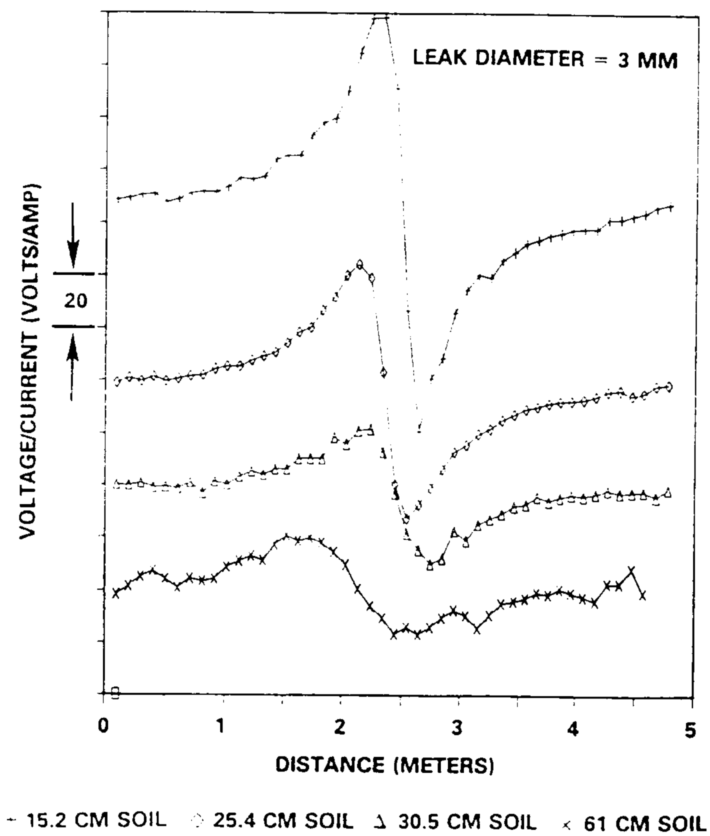


Figure 11
Leak Signals for Various Thicknesses of Soil Cover

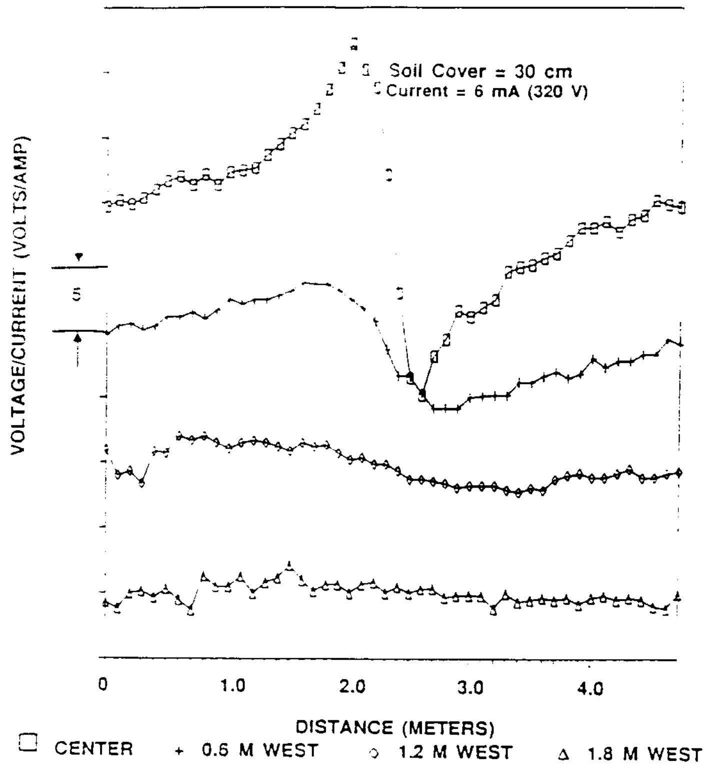


Figure 12
Leak Signals with 0.3m of Soil Cover for Offset Scan Lines

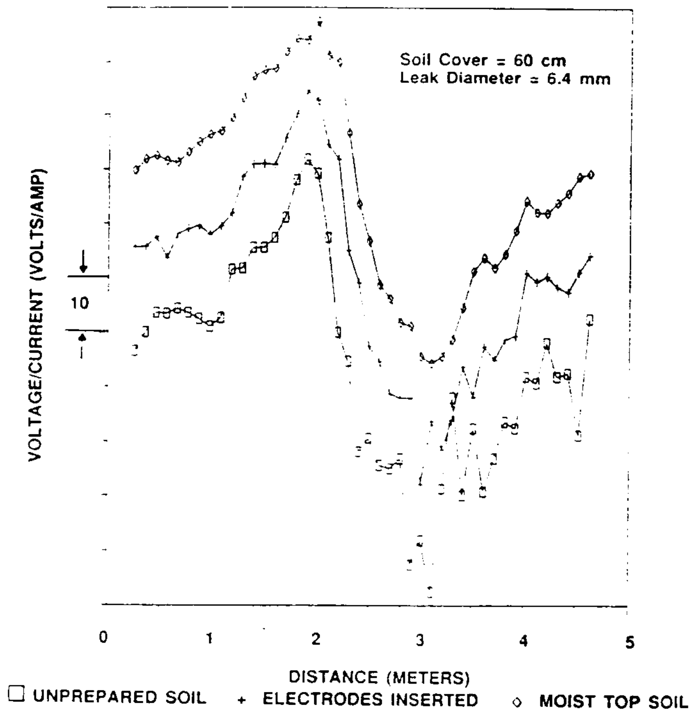


Figure 13
Improvement in Leak Signal Quality When the Soil is Prepared

TYPES OF SURVEYS AND SURVEY TECHNIQUE

Survey of Bottom of Water-Covered Single Liners or Secondary Liners

When a single liner is in place, the leak location power supply is connected to a source electrode in the water and a grounded electrode. Surveys are conducted along survey lanes established across the impoundment. The most convenient method of operation is to place the lines across the shorter dimension of the impoundment and perpendicular to a straight side. Survey lines are spaced approximately 5m apart. Sufficient accuracy usually is obtained using only a tape measure. Marks are put on the liner above the water line every 5m on the opposite sides of the impoundment. Floating polyethylene ropes or non-conducting survey chains are stretched between opposite marks across the impoundment. As an alternative procedure, the panel seams can be used as the survey lanes. Two or three survey operators can scan the length of a panel with overlapping coverage by observing or feeling the seams. This alternative procedure is more difficult or impractical to implement with irregular panel layouts.

Horizontal traverse lines are scanned with a coverage of 2.5m on each side of the traverse lines. The probe is scanned along the bottom in an arc overlapping under the traverse line and past the midpoint of the survey lane. After each arc is swept, the operator moves forward approximately 0.3m and scans a return arc to just beyond the traverse line. The leak detection probe is thus scanned within no more than approximately 0.15m of every submerged point on the liner. The threshold control on the leak location electronics is adjusted frequently to maintain maximum leak detection sensitivity.

Leaks are indicated by a sudden increase in the frequency of the tone in the earphone as the electrode is scanned near the leak. When a leak is detected, the threshold and sensitivity controls are adjusted to obtain a peak on-scale meter reading both laterally and longitudinally when the tip of the probe is scanned. This procedure determines the exact location of the leak. The probe tip is held on the leak while the probe is swung to vertical. The leak is then marked with lead sinkers connected to a small float with a length of string.

The locations of the leaks also are measured relative to a temporary survey grid for a permanent record. Where practical, the location and type of leak also is noted (i.e., on a seam or patch, or in the panel). In addition to covering every square meter of the liner, all liner field seams and patches are double checked.

Survey of Bottom of Water-Covered Primary Liners

By placing the current return electrode in electrical contact with the liquid-saturated drainage layer located between the two liners, the electrical leak location method can be used to locate leaks in the upper liner. The survey procedures for a single liner are then followed. Simple electrical continuity tests between the drainage layer and the earth also can determine the existence of leaks in the bottom liner but not their location.

Survey of Side Slopes

Surveys of water-covered side slopes are accomplished using the probe with a long handle and small wheels to support the electrodes. The side slope area is surveyed by systematically lowering the probe down the slope and then pulling the probe up the slope. The operator moves forward approximately 0.3m between sweeps. Each survey sweep covers an area approximately 0.3m wide down the flooded sidewall. Any leaks found are accurately located, and the locations are referenced to a temporary survey grid established on the berm.

When more than approximately 7m of the side slope are immersed, the manual survey of the side slopes is conducted in stages. The water level is raised or lowered in stages that allow approximately 7m of the immersed side slope to be surveyed at a time. The surveys should provide overlapping coverage between the stages.

The side slopes can be surveyed by raising or lowering the water level in stages either before or after the bottom of the liner is tested. If the side slopes are tested first, from the top down, the cell will be filled with water to the working level prior to the leak location survey. This procedure exposes the liner to loads representative of actual in-service loading. Usually the level of the water can be lowered faster than it can be raised, therefore, the survey can be completed with less standby time as the water level is adjusted.

The advantage of surveying the side slopes after the bottom of the liner is surveyed is that washout or settling of the subgrade under the liner caused by possible large leaks in the bottom of the liner might be avoided if leaks in the bottom are located and repaired prior to full hydrostatic loading. However, there is no assurance that additional leaks will not occur because of the increased hydrostatic loading during the side slope survey. Therefore, additional testing of the bottom of the liner may be required after the side slopes are surveyed.

Survey of Soil-Covered Liners

Often a layer of sand or soil is placed on the liner to serve as a protective layer or drainage layer. Geomembrane liner material is also covered with soil when used for landfill final cover systems. Because of the high probability of damaging the geomembrane liner in the process of emplacing the soil, a leak location survey of the soil-covered geomembrane is a highly effective method of ensuring the integrity of the liner. The electrical leak location method is the only method capable of locating leaks in a geomembrane covered with protective soil. The method is particularly valid because the liner is tested under load and after the liner has been exposed to possible damage incurred in the process of emplacing the protective soil cover.

The electrical leak location method was modified to make surface soil potential measurements to locate leaks in geomembranes covered by a protective or cap soil layer. The soil is dampened with water to allow good electrical contact and allow the water to percolate through the leaks. Completely flooding the liner is not necessary. Surface potential measurements are made using a portable digital data acquisition system. Surveys are conducted by making potential measurements on closely spaced survey lines. Point-by-point potential readings are made along the survey lines with a fixed measurement electrode separation. The data are downloaded to a computer for storage and plotting. When a suspect area is located, manual measurements are made to further isolate the leak. When the surface of the soil is dry, the dry soil is scraped away so that accurate measurements can be made on the uncovered moist soil.

The data are examined for leak signatures. The characteristic leak signal is a bipolar signal with the initial signal deflecting opposite to the polarity of the current injection electrode. Signals caused by other features such as drainage laterals can be recognized and rejected.

The leak location sensitivity increases as the thickness of the soil decreases. Typically, leaks with a diameter greater than 0.3cm can be located in a geomembrane covered with 0.3m of soil. Testing for leaks with only a portion of the soil cover in place is recommended if the thickness of the soil cover will be greater than approximately 0.3m. Any possible damage to the liner will most likely occur during the installation of the first layer of soil.

The leak location accuracy for surveys conducted with soil cover depends upon several factors including the closeness of the spacing of the point-by-point measurements and the homogeneity of the soil cover. A practical accuracy guideline for leak location surveys with soil cover is approximately one half of the soil thickness. After the soil has been removed, followup measurements can be made to locate the leak within 1.5 cm.

The survey parameters (survey line spacing, spacing of measurements and spacing of measurement electrodes) must be designed for proper coverage and leak detection sensitivity. The design of the surveys must be based on the physics of the electrical leak location method.

Another survey methodology can be successful in some cases, particularly when an electrical leak location was previously conducted with the liner flooded with water and only a few major leaks are suspected. Rather than performing a systematic survey on closely spaced survey lines to locate smaller leaks, the reconnaissance measurements are intended to attempt to isolate a few large leaks in the hope that no smaller leaks are present. The measurement sequence is to locate a leak, remove the soil from over the leak, insulate the leak and then measure the power supply current. This sequence is repeated until the current level decreases to a low level indicating that all of the major leaks are found.

Multi-Channel Leak Location Surveys

Southwest Research Institute has developed a multi-channel leak location system for locating leaks in impoundments with hazardous wastes, for locating leaks in the side slopes of deep impoundments in one stage and for surveying in deep water. The system is particularly cost-effective for large impoundments and landfills. The new system has 12 weighted electrodes suspended from a nonconducting horizontal axle between two large plastic wheels. Twelve data acquisition channels, a serial data telemetry system and a portable computer or multi-channel chart recorder are used to acquire, display and record the leak location data.

The sensor assembly is systematically pulled across the bottom of the impoundment using a power winch. Each survey sweep covers an area approximately 4m wide. If feasible, the sweeps are referenced to liner seams to provide overlapping coverage of the seams as well as complete coverage of the water-covered liner panels. The locations of the leaks are referenced to a temporary grid system established on the berm of the impoundment.

The leak location data acquisition system has been applied at one large impoundment to survey the 18-m-long side slopes. The sensor and electronics subsystems operated properly and located several leaks. Mechanical modifications are needed to make the assembly more rugged.

Remote-Controlled Leak Location Survey System

A small remotely-controlled boat equipped with potential measurement electrodes and electronics, servo-controlled steering and data telemetry has been developed to locate leaks in hazardous waste impoundments. In one mode, the measured potentials are used with the servo-controlled steering to automatically seek leaks. The system has been constructed and tested in a geomembrane test impoundment. The method is described in U.S. Patent 4,719,407 for Automated Search Apparatus for Locating Leaks in Geomembrane Liners.

SITE PREPARATIONS

Water Covering the Liner

To conduct a leak location survey of the bottom of the liners, a minimum of 0.15m and a maximum of 0.75m (0.6m preferred) of water containing no hazardous or foul substances must cover the liner. Because hydrostatic loading produces mechanical stress in both the seams and the material, leaks may occur only after the liner is subjected to these loads. Therefore, testing the liner after the impoundment has been filled with water is a valid method for determining if leaks will occur under realistic loading conditions.

The depth of the water for the survey (within the specified range) can be determined on a case-by-case basis. Surveying with a shallow water level requires less water and pumping, but limits the hydrostatic loading. The survey covers only the submerged liner area when the cell is filled with water to the depth specified for the survey. Therefore, surveying with shallow water decreases the amount of the side slope that is covered by water and thereby limits the area of survey coverage for the cases where all of the side slopes are not surveyed.

Flooding the Leak Collection Zone

To survey the primary liner of a double liner system, an electrical conduction path through any leaks to the leak collection zone must be established. This process can be accomplished by pumping water in the leak collection system while the primary liner is being filled with water. Water can be pumped into the discharge side of the leak collection system. In some cases, air vents must be provided in the perimeter edges of the primary liner near the top of the berm to allow air trapped between the two liners to be vented. The water also can be pumped into the air vents. The water level in the leak collection zone must be slightly below the level of the water in the primary liner to prevent the primary liner from being lifted.

In some cases when moist sand is used in the leak collection zone, an alternative method can be used to establish the electrical conduction path without flooding the leak collection zone. The reliability of this alternative method depends on the type and moisture content of the sand. The alternative method is to allow the water from the leaks to percolate through the leak collection zone. This method is most effective when the water on top of the liner has been allowed to stand at least 3 days and good electrical contact can be established with the current electrode in the leak collection zone.

Current Electrode in Leak Collection Zone

Provisions should be made to allow the placement of a metal electrode into the leak collection zone of a double liner system. In some cases, a slit is cut in the liner above the water level to allow the insertion of the metal electrode. This slit must be repaired when the leaks are being repaired. In some installations, the electrode can be inserted through a straight plastic pipe that extends down into the leak collection sump.

A third method for providing the electrode is to install a permanent electrode constructed of approximately 0.1m^2 of thin stainless steel sheet in the drainage layer near the lowest point of the leak collection system. The corners and edges of the electrode should be rounded to prevent damage to the liner. In addition, the electrode can be wrapped with geotextile or geonet to further protect the liners. An insulated wire (16 AWG to 12 AWG) must be connected between the electrode and a test terminal located at a convenient, accessible site near the impoundment. The connections should be insulated with a suitable coating.

Isolate Electrical Paths Through the Liner

The electrical leak location method locates leaks by detecting electrical conduction paths through leaks in the liner. If feasible, any other electrical conduction paths through or around the liner must be eliminated or insulated. All penetrations, such as fill lines, drain pipes, batten anchors, penetration flanges, footings, pump lines, pump wiring, instrumentation wiring, instrumentation conduits and access ramps making contact with the water in the liner should be insulated from ground or constructed of an insulating material. Electrical paths also can be established through the liquid in plastic pipes if the pipes connect to a grounded metal valve or metal pipe.

Rubber packers can be placed in plastic drain and fill pipes to insure that the fluid in the pipes does not act as an electrical path to ground. In some cases a temporary geomembrane cover can be seamed over pipes and batten anchor bolts. Metal pipes penetrating the liner can be insulated using large plastic garbage bags or caps constructed of insulating foam rubber, geomembrane and plywood.

For the electrical paths to be a factor, the paths must form a conduction path through or around the liner being surveyed. The presence of such electrical conduction paths does not preclude the application of the method. However, if these paths can not be eliminated, isolated or insulated, the paths will be indicated as leaks that may mask the signal from other smaller leaks in their immediate vicinity. In addition, if the conduction paths are substantially lower in resistance than the electrical paths through the leaks, the amount of current flowing through the leaks may be too small to detect small leaks. The design and construction of the impoundment can be reviewed to determine the best methods to eliminate or minimize the effect of these conduction paths on the survey.

Remove Debris

For safety and better leak location reliability, debris such as unnecessary sand bags and non-floating liner material must be cleared from the liner.

Conducting Structures

A leak is indicated as an electrical potential anomaly in an otherwise relatively uniform potential distribution. Conducting structures such as concrete footings, metal supports and sand bags can distort the potential distribution, making leaks more difficult to locate. Small leaks that are substantially covered by structures such as a concrete footing probably cannot be detected. Moderate-size leaks at the perimeter of such structures can usually be detected.

Power Requirements

Electric power of single phase 95 to 125 V AC, 45 to 70 hertz, at approximately 5 amp must be provided at the site for operation of the leak location power supply. The power outlet should be located at the top of the berm.

SAFETY

A potential for injury is present in any work at a construction site. Specific hazards include electrocution, slipping and falling on the geomembrane material, falling in the water, hypothermia and drowning. Job safety is the most important aspect of doing a complete and through leak location survey. Proper safety precautions must be followed.

In addition to the standard construction site safety rules, specific safety procedures must be used to safely conduct an electrical leak location survey using a high voltage power supply. The survey operators wading in the water are exposed to an electrocution hazard if they come in contact with a grounded electrical conductor. Precautions must be taken to avoid this possibility. Some precautions include using only dry electrically-insulating hand lines for entering or exiting the basin and being sure that wire rope, wet rope, metal cables, electrically-conducting poles, electrically-conducting ladders, or any other electrically conducting objects are not available or used for rescue or used to aid personnel in the water.

A safety circuit for the high voltage power supply provides a measure of protection in case of accidental contact of personnel with the high voltage. Because making the power supply inherently safe and making the safety circuit completely reliable are not possible, survey procedures and procedures should be such that personnel can never make electrical contact across the power supply. The safety circuit must absolutely never be tested by human contact. The safety interlocks must not be bypassed to allow operation of the power supply without the flashing red safety strobe.

Other elements of an effective safety plan include proper training of survey personnel, safety briefing for visitors to the site, high-voltage warning signs and employing personal flotation devices for operations near deep water. The water in the impoundment must be non-hazardous if an operator is to be completely immersed. Surveys must never be performed when there is a threat of lightning or under adverse weather conditions such as cold weather, rain, or snow or where the operator has difficulty concentrating on safety.

On some work sites, the survey operators must be qualified to meet OSHA 29 CFR 1910.120 safety requirements. This OSHA regulation requires 40 hr of instruction, on-the-job-training, a medical surveillance program and annual 8 hr training refresher courses.

Operators should be trained in first aid and cardiopulmonary resuscitation. Additional safety procedures must be followed depending on the hazards and conditions present at each site.

SPECIFYING ELECTRICAL LEAK LOCATION SURVEYS

The Appendix is a guide for specifying electrical leak location surveys. The guide offers suggestions for typical surveys as well as assigning responsibilities for preparations for the surveys.

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APPENDIX

Specification Guide for the Electrical Leak Location Method
For a Geomembrane Leak Location Survey
With No Soil Covering the Liner

Introduction

This list of typical specifications is presented with relevant general discussion to explain the preparations required for surveying primary or secondary liners for leaks using the electrical leak location method. Electrical leak location surveys can be contracted for by the owner or operator of the facility, the general contractor, a third-party quality assurance contractor, or the liner installer. ***To best serve the interests of the facility owner, the electrical leak location surveys should be contracted for by the owner or operator of the facility, or a third-party quality assurance contractor. The following specifications are written for this type of contractual arrangement. Separate specifications are required for the general contractor and for the electrical leak location contractor.***

The specifications are for a manual survey of liners with no soil or sand covering the liner. The specifications are intended for guidance and reference only. They are not intended to be all-inclusive, to be necessary in every application, or to recommend any particular practices or procedures. The specifications for each installation should be written specifically for the application, using proper engineering practices and judgement and legal advice and review. ***Each use of the designations of Company and Contractor should be reviewed and changed as applicable to refer to the owner of the facility, the general contractor, the liner installer, an independent quality assurance consulting firm, or other subcontractor as applicable. Other terms such as landfill, impoundment or pond should be used as appropriate. The specifications are written to be very comprehensive. They should be abbreviated wherever possible. The paragraphs typed bold are provided for explanation and can be omitted from the specification.***

Electrical Leak Location Survey Specifications for General Contractor

Electrical Leak Location Survey
Under Hydrostatic Load

An electrical leak location survey will be performed by Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78238, (Contact Daren L. Laine, telephone 512-522-3274) or approved equivalent. The survey will be conducted on the bottom and side slopes of both the primary and the secondary geomembrane liners of the basin. Contractor will be responsible for preparing the basin for the survey as described below.

If more than one leak per 2000 ft² of surveyed area is found in either liner, the leak location survey will be limited to one man-day of survey per 20,000 ft² of liner material. **The electrical leak location survey will be conducted to better categorize the occurrence of leaks and possible causes of leaks to aid in the specification of corrective measures. The electrical leak location survey will be curtailed until the cause of the leaks is determined and corrective measures are taken by the Contractor. In the case of defective seaming, only patching the leaks will not be a viable corrective action because additional leaks will likely form when basin is put in service. If more than one leak** per 2000 ft^2 of surveyed area is found in either liner, an electrical leak location survey of the liner will be performed at the expense of the Contractor after the corrective actions are taken and the located leaks are repaired.

The occurrence of greater than approximately one leak per 2000 ft^2 can indicate defective seaming process or procedures, defective liner material, or ineffective liner material handling or protection measures. In these cases, further electrical leak location surveying are not sensible because the questionable integrity of the installation. In these cases corrective actions must be taken.

Prior experience indicates that detectable leaks are found in some repaired leaks when they are tested using the electrical leak location method. When significantly less than approximately one leak per 2000 ft^2 of liner is found, rechecking the leaks with the electrical leak location method is usually not necessary if the leak is sealed and then a patch is seamed over the repair. The repair can then be tested using a vacuum box. When more than approximately one leak per 2000 ft^2 are found, rechecking the seams and patches using the electrical leak location method is warranted. The geomembrane installer is responsible for making the repairs.

Preparing the Basin for Survey

Electrical Paths Through the Liner

Contractor shall electrically insulate electrical conduction paths through the liner. Such conduction paths can be caused by fill pipes, drain pipes, batten anchors, penetration flanges, footings, pump lines, pump wiring, instrumentation wiring, instrumentation conduits and access ramps. Electrical paths can also be established through the liquid in plastic pipes if the pipes connect to a grounded metal valve or metal pipe. Contractor will provide any necessary rubber packers and/or insulated coverings for this purpose. Properly supported temporary geomembrane material sealed over the electrical penetrations can also be used.

The electrical leak location method locates leaks by detecting electrical conduction paths through leaks in the liner. Any other electrical conduction path which also makes a circuit through or around the liner will give the same indication as a leak. The presence of such electrical conduction paths does not preclude the application of the method. However, if these paths can not be eliminated, isolated, or insulated, they will be indicated as leaks and they may mask the signal from other smaller leaks in their immediate vicinity. In addition, if the conduction paths are substantially lower in resistance than the electrical paths through the leaks, the amount of current flowing through the leaks may be too small to allow the detection of small leaks.

Electrode in Leak Collection Zone

Contractor shall make the arrangements for placing a suitable metal electrode in the leak collection zone prior to installing the primary liner. The electrode shall be constructed of approximately 1 ft^2 of stainless steel sheet. The corners and edges of the electrode must be rounded to prevent damage to the liner. In addition, the electrode shall be imbedded in the sand or wrapped with geotextile or geonet to further protect the liners. An insulated wire (16 AWG to 12 AWG) must be connected between the electrode and a test terminal located at a convenient accessible location near the basin. The connections must be insulated with a suitable coating. The electrode shall be buried at a depth approximately 2 in above the secondary liner near the lowest point of the collection system.

Some alternative methods include cutting a slit in the liner a few feet above the water level to allow the insertion of the metal electrode. The Contractor shall be responsible for having slits cut for inserting the electrode if necessary and repairing the slits. Where necessary and feasible, a rod-shaped electrode can be placed in a leak sampling pipe that extends down into the leak collection sump. However, this last method is usually not as effective as the other methods because of the danger of getting the electrode stuck and the increased resistance of the water in the pipe.

Flooding the Liner

Contractor shall flood the liner to the required depths with water containing no hazardous or foul substances. A source of water will be provided by the Company. Water disposal facilities will be provided by the Company. Contractor will be responsible for pumping or otherwise transferring the water. Contractor will be responsible for damage to the subgrade or berm caused by water leakage and erosion, or hydrostatic loading. Provisions must be provided and procedures shall be followed by the Contractor to minimize the dynamic loading of the liner and possible damage to the liner, leak collection system and/or subgrade caused by the water stream or by a rapid change in the water level. Prior to flooding, Contractor shall clean the basin of debris including scraps of liner material, other construction materials and unneeded sand bags.

The water is needed for the electrical leak location method. The hydrostatic loading of the liner is also desirable for determining if leaks will occur under realistic loading conditions.

The basin shall be filled with the water to the working depth. When more than approximately 20 ft of the side slope is immersed, the manual survey of the side slopes is conducted in stages. The Contractor shall lower the water between each survey stage to allow no more than approximately 20 ft of the immersed side slope to be surveyed at a time. If the water can not be lowered to the level required for the next stage of the survey within 16 hr, Contractor shall pay Company for standby time or additional reduced mobilization costs for the electrical leak location survey contractor.

In some cases where the basin is large, or the discharge rate for the water must be limited, standby time or additional reduced mobilization costs are inevitable and should be planned and contracted for as part of the contract with the electrical leak location contractor. In those cases, the Contractor shall pay Company only for additional standby time or additional mobilization costs due to delays caused by the Contractor in excess of the planned amount.

The side slopes can be surveyed by raising or lowering the water level in stages either before or after the bottom of the liner is surveyed. If the side slopes are surveyed first, from the top down, the basin will be filled with water to the working level prior to the leak location survey. This exposes the liner to loads representative of actual in-service loading. In most cases the level of the water can be lowered faster than it can be raised, therefore, the survey can be completed with less standby time required while the water level is adjusted.

The advantage of surveying the side slopes after the bottom of the liner is surveyed is that washout or settling of the subgrade under the liner caused by leaks in the bottom of the liner might be avoided if leaks in the bottom are located and repaired prior to full hydrostatic loading. However, there is no assurance that additional leaks will not occur because of the increased hydrostatic loading during the side slope survey. Therefore, additional surveying of the bottom of the liner may be required after the side slopes are surveyed.

After the side slopes have been surveyed to the toe of the berm at the most shallow part, the Contractor shall lower the water to the level where the most shallow portion of the bottom of the basin is covered with approximately 6 in of water. When the bottom of the liner slopes more than 30 in, the survey of the bottom shall be conducted in more than one stage. The Contractor shall lower the water between each survey stage to allow the bottom of the basin to be surveyed in no more than 30 in of water. The water level is lowered to the level where the most shallow unsurveyed area is covered with 6 in of water. If the water can not be lowered to the level required for the next stage of the survey within 16 hr, Contractor shall pay Company for standby time or additional reduced mobilization costs for the electrical leak location survey contractor.

Again, for the cases where the basin is large, or the discharge rate for the water must be limited, standby time or additional reduced mobilization costs should be planned and contracted for as part of the contract with the electrical leak location contractor. In those cases, the Contractor shall be liable for paying only for additional standby time or additional mobilization costs due to delays caused by the Contractor in excess of the planned amount.

Flooding the Leak Collection Zone for the Survey of

The Primary Liner

Contractor shall also flood the leak collection zone with water. This can be done by pumping water in the leak collection system while the primary liner is being filled with water. To avoid possible damage, the water level in the leak collection zone must be maintained below the level of the water in the primary liner to prevent the primary liner from being lifted. Water can be pumped into the discharge side of the leak collection system. Air vents must be provided in the perimeter edges of the primary liner near the top of the berm to allow air trapped between the two liners to be vented. The water can also be pumped into the air vents. The Contractor shall be responsible for having slits cut for flooding and air vents, if necessary and repairing the slits.

To survey the primary liner, an electrical conduction path through any leak to the leak collection zone must be established. This task is usually accomplished by flooding the leak collection zone. In some cases when sand is used in the leak collection zone, an alternative method can be used to establish the electrical conduction path. The reliability of this alternative method depends on the type and moisture content of the sand. The alternative method is to allow the water from the leaks to percolate through the leak collection zone. This method is most effective when the sand has residual moisture and the water on top of the liner has been allowed to stand at least three days and good electrical contact can be established with the power supply electrode in the leak collection zone.

The survey of the secondary liner must be conducted prior to installation of the primary liner. However, because the secondary liner is in direct contact with earth ground there is no requirement to flood the subgrade under the liner.

Electrical Power

Contractor will furnish a source of electrical power of 110-120 V AC at 10 amp for the electrical leak location equipment. The power outlet shall be located at the top of the berm.

Safety

Proper safety precautions and safe working practices shall followed. A written safety plan specifically addressing the electrical leak location surveys submitted by the electrical leak location contractor shall be followed. Contractor will also inform the electrical leak location survey subcontractor of the specific safety rules, procedures and hazards at the plant site.

Electrical Leak Location Survey Specifications For Electrical Leak Location Contractor

Electrical Leak Location Survey Under Hydrostatic Load

An electrical leak location survey will be performed by Southwest Research Institute, 6220 Culebra Road, San Antonio, Texas 78238, (Contact Daren L. Laine, telephone 512-522-3274) or approved equivalent. The survey will be conducted on the bottom and side slopes of both the primary and the secondary geomembrane liners of the basin. Contractor will be responsible for preparing the basin for the survey as described below.

The survey equipment leak detection distance shall be verified prior to the survey. The results of the verification tests shall be used to determine the distance between survey scans. The verification test will be conducted using a simulated leak assembly as shown in Figure 1. The simulated leak consists of a sealed plastic container with an insulated wire penetrating the container through a sealed hole in the container. The insulation at the end of the wire is stripped off for a distance of approximately 1 in. The opposite end of the wire is connected to a grounded electrode or a separate electrode in the leak collection zone. A weight is placed in the container and the container is filled with a sample of water from the basin being tested. A sample of geomembrane liner with the same thickness as the liner being tested is sealed behind a large hole in the lid of the container. A 0.03 in nominal diameter circular leak is placed in the center of the geomembrane sample by penetrating the liner with a heated No. 6 sewing needle (0.030 in nominal diameter) or a sewing pin (0.034 in nominal diameter).

The simulated leak assembly will be placed in the water in the basin and survey sweeps will be made as the operator approaches the simulated leak. The distance from the leak locator probe to the leak when the leak is just detectable is measured. This is the leak detection distance. Twice this distance will be the maximum distance between survey scans. The power supply electrode can be put at any position in the basin, but the survey must be conducted with the power supply electrode no farther from the leak than the distance when the verification test was conducted.

The leak location sensitivity is proportional to the resistivity of the water used to flood the liner and the power supply voltage. For relatively high resistivity water such as river or lake water, or water from a municipal supply, the simulated leak can be usually be detected at a distance of approximately 18 in. For a saturated brine solution, the simulated leak can usually be detected from a distance of 6 in. Smaller leaks will be detected if the leak location probe electrode happens to pass directly over the leak. Larger leaks can be detected from greater distances. However, these typical leak detection sensitivities can be greatly reduced in some instances and some judgement is necessary for specifying an effective survey for a reasonable cost.

If more than one leak per 2000 ft^2 of surveyed area is found in either liner, the leak location survey will be limited to one man-day of survey per 20,000 ft^2 of liner material. The electrical leak location survey will be conducted to better categorize the occurrence of leaks and possible causes of leaks to aid in the specification of corrective measures. The electrical leak location survey will be curtailed until the cause of the leaks is determined and corrective measures are taken by the Contractor. In the case of defective seaming, only patching the leaks will not be a viable corrective action because additional leaks will likely form when basin is put in service. If more than one leak per 2000 ft^2 of surveyed area is found in either liner, an electrical leak location survey of the liner will be performed at the expense of the Contractor after the corrective actions are taken and the located leaks are repaired.

The occurrence of greater than approximately one leak per 2000 ft^2 can indicate defective seaming process or procedures, defective liner material or ineffective liner material handling or protection measures. In these cases, further electrical leak location surveying is not sensible because the questionable integrity of the installation. In these cases corrective actions must be taken.

Prior experience indicates that detectable leaks are found in some repaired leaks when they are tested using the electrical leak location method. When significantly less than approximately one leak per 2000 ft^2 of liner is found, rechecking the leaks with the electrical leak location method is usually not necessary if the leak is sealed and then a patch is seamed over the repair. The repair can then be tested using a vacuum box. When more than approximately one leak per 2000 ft^2 is found, rechecking the seams and patches using the electrical leak location method is warranted. The geomembrane installer is responsible for making the repairs.

Preparing The Basin For Survey

The Company is responsible for having the basin prepared for the electrical leak location survey. These preparations include: electrically isolating electrical conduction paths; placing a suitable metal electrode in the leak collection zone prior to installing the primary liner; cleaning the basin of debris; flooding the liner to the required depths with water; adjusting the level of the water as necessary; flooding the leak collection zone with water; and furnishing a source of electrical power.

Leak Location Surveys

Electrical Leak Location Survey of Sidewalls of the Secondary and Primary Geomembrane Liners of the Basin

The electrical leak location survey contractor shall conduct a leak location survey of the side slopes of the secondary liner and the primary liner using the electrical leak location method. The side slope area will be surveyed by systematically scanning the side slopes. Procedures shall be followed to assure that the leak detection probe is scanned within the detection distance for every point on the submerged liner. Twice the leak detection distance is the maximum distance between survey

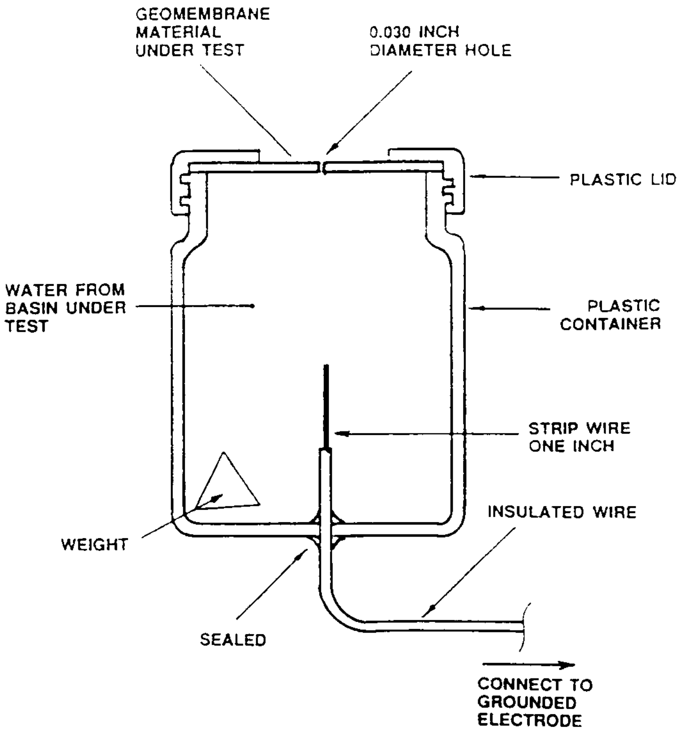

Figure 1
Simulated Leak Assembly

scans. In addition, all of the seams oriented down the side slopes shall be surveyed individually by scanning the leak location probe along the seam.

When more than approximately 20 ft of the side slope is immersed, the water must be lowered in stages to allow the manual survey of the side slopes. Any leaks found will be accurately located and the locations will be referenced to reference marks on liner near the berm of the basin.

Electrical Leak Location Survey of Bottom of the Secondary and Primary Geomembrane Liners Basin

The electrical leak location contractor shall conduct a leak location survey of the bottom of the secondary liner and primary liner using the electrical leak location method. Procedures shall be followed to assure that the leak detection probe is scanned within the leak detection distance of every submerged point on the liner. In addition, all of the seams shall be surveyed individually by scanning the leak location probe along the seam.

Detected leaks shall be located to within 0.5 in or less and immediately marked with lead sinkers and floats. The location of the leaks shall also be measured relative to reference marks on the berm or side slope of the liner for a permanent record. Where practical, the location and type of leak shall be noted (i.e. on a seam or patch, or in the panel).

Reports, Safety And Other Points

Reports

If requested, the general results of the electrical leak location survey shall be reported to the designated representative of the Company during the daily progress of the field work. A list of the locations of the leaks found shall be submitted to the designated representative of the Company after completion of the field work and before the electrical leak location survey crew leaves the site. A letter report documenting the work, including a brief summary of the survey procedures, results of the survey and problems encountered shall be prepared and submitted within 14 days after completion of the field work.

Safety

Proper safety precautions and safe working practices shall be followed. A written safety plan specifically addressing the electrical leak location surveys shall be submitted to the Company for approval by the electrical leak location contractor prior to the start of the leak location field work. The safety plan shall be followed. Contractor and Company will inform the electrical leak location survey subcontractor of the specific safety rules, procedures and hazards at the plant site.

Confidentiality

Unless agreed to in writing, the name of the facility, the location of the facility, the identity of the Company, Contractor and the geomembrane installer shall be held in strict confidence. Any published results of the survey will include only leak statistics. Information shall not be afforded confidentiality if: such information is publicly available or rightly obtained without restriction by from a third party; or released without restriction by the furnishing party to anyone, including the United States Government.

Some facility owners prefer to avoid publicity concerning their operations. A confidentiality agreement should describe the level of security desired.